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# Biodiversity Conservation and Ecosystem Services of Forests in Siwaliks of Northern India

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## ABSTRACT

Biodiversity loss is one of the world's most pressing crises. Biologically rich and unique habitats are being destroyed, fragmented, and degraded due to increasing human population, resource exploitation and environmental pollution. Conservation of forest biodiversity is fundamental for sustaining forests, and supporting the livelihoods of people and their economic well-being. The ecosystem services that benefit the society are improving air quality, climate regulation, carbon sequestration, water purification, pollination, and prevention of erosion, besides provision for useful biomass. Innovative and effective responses are necessary to meet the challenges of forest biodiversity conservation for the well-being of the people. Therefore, it is important to maintain the forests as ecosystem service provider systems for food, timber, energy, and biodiversity. This paper gives an overview of plant biodiversity, biodiversity conservation mechanisms, and carbon storage as an indicator of ecosystem services in forests of the Siwaliks in northern Haryana. The relationships between biodiversity conservation, poverty alleviation, ecosystem services, and forest biomass production are emphasized. The role of integrated watershed management for human well-being for bioresource conservation in the Siwalik foothills are discussed.

*Key Words*: Biodiversity; Ecosystem Services; Poverty Alleviation; Forest Biomass; Economic Sustainability

## INTRODUCTION

Biodiversity plays a key role in regulating ecosystem function and stability and hence, is essential for human survival and economic well bein. The UN Convention on Biological Diversity defines biodiversity as "the variability among living organisms from all sources, including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (UNEP 1992). Humans derive many direct and indirect benefits from the rich biodiversity of diverse types of ecosystems. Biodiversity is the source of food, medicines, pharmaceutical drugs, fibres, rubber, timber and natural products that sustain global trade. The diversity of organisms also provides many ecological services free of charge that are responsible for maintaining ecosystem health and human welfare. The over-exploitation of ecosystems is evident at local to global scales with profound negative impacts on biological diversity and livelihood opportunities of the people along with their cultural diversity.

The ecosystem services that benefit society are air quality, climate regulation carbon sequestration, water purification, pollination, and prevention of erosion and have been valued in the range of 16 to 54 trillion ($10^{12}$) US dollars per year (Costanza et al. 1997). The Millennium Ecosystem Assessment defined four categories of ecosystem services, i.e., provisioning services, regulating services, cultural services and supporting services that contribute to human well-being (MA 2005). The ecosystem services approach can save many ecosystems with high biodiversity and willingness of society to protect their biodiversity. TEEB (The Economics of Ecosystems and Biodiversity) is a major global programme to draw attention to the tangible benefits of biodiversity, and highlights the growing costs of biodiversity loss and ecosystem degradation (TEEB

2010). The Convention on Biological Diversity, the Millennium Development Goals, and other international agreements have clearly indicated relationship between biodiversity conservation, poverty alleviation, and human well-being (MEA 2005, Sachs et al. 2009, Turner et al. 2012).

There is need to develop strategies to protect biodiversity so as to achieve the goals of poverty reduction and sustainable development. Forest plays an important role in maintaining ecological processes as well as in providing livelihood and supporting economic growth (FAO 2010). More than 1.6 billion people rely on forests and non-timber forest products for their livelihoods.; wood and other goods removed from the forests have been valued at 122 billion US dollars in 2005 (FAO 2010). The forests are the home to 78% of the land biodiversity, and are among the most biodiverse terrestrial ecosystems (FAO 2010 , IUCN 2010). Habitat degradation and the loss of biodiversity are threatening the livelihoods of more than 1 billion people living in dry and sub-humid lands globally. Singh and Kushwaha (2008) have given an overview of forest biodiversity and its conservation in India and stressed the need for people's participation in biodiversity conservation and rehabilitation

This paper gives an overview of biodiversity and ecosystem services in the forests of the Haryana Siwaliks in northern India. It also aims at discussing the relationships between biodiversity conservation, and ecosystem services.

## BIODIVERSITY IN FORESTS OF HARYANA SIWALIKS

The forest and tree cover in India is 78.29 million ha in 2011, which is 23.81% of the total geographical area according to State of Forest Report 2011. This includes 2.76% of tree cover (FSI 2011). Out of total forest cover, about 2.54% are very dense forests, 9.76% are moderately dense forests and 8.75% are open forests (FSI 2011). The National Forest Policy 1988 has given clear direction and guideline for forest conservation and afforestation in India. There are large anthropogenic demands on forest resources in different regions of India because more than 200 million people are dependent on forests for livelihoods.

The total forest area in the Yamunanagar is 193 $km^2$ which forms 10.92% of the total geographical area of the district (FSI 2009). The total forest area in Panchkula forest division is 400 $km^2$ which forms 30.55% of total geographical area of the district (FSI 2009). The Yamunanagar and Panchkula forest divisions are located in north-eastern part of Haryana State in Siwalik region, the foot hills of western Himalaya (Figure 1). The Kalesar reserve in the Yamunanagar forest divisions is comprised of the National park, Kalesar Wildlife Sanctuary and the mixed land-use system. The Kalesar Reserved Forest was declared a wildlife sanctuary in 1992 and later a National Park in 2003. The river Yamuna runs on the east of the Kalesar National park and the Wildlife Sanctuary. The forests are mainly composed of dry Siwalik *Shorea robusta* forest, dry plains *Shorea robusta* forest, northern dry mixed deciduous forests, dry tropical riverine forests, and the plantation forests (Champion and Seth 1968, ICFRE 2013). The forests in Panchkula forest division are Northern dry mixed deciduous forests, dry deciduous scrub and subtropical Siwalik chir-pine forest (Champion and Seth 1968, ICFRE 2013). The vegetation composition of major forest types is given in Table 1.

Trees form the major structural and functional basis of tropical forest ecosystems and can serve as robust indicators of changes and stress at the landscape scale. Plant diversity at local scale has been studied by using various indices, such as number of species per unit area (species richness) or the Shannon index. These are used as indicators of the degree of complexity of a community and provide information on the homeostatic capacity of the system to unforeseen environmental changes (Magurran 1988).The Shannon's diversity index (H), Margalef's index (D), Simpson's index (Cd) and Pielou index (e) of diversity for the trees in the plains *Shorea robusta* forest, Siwalik *Shorea robusta* forest, and the dry mixed deeciduous forest are given in Table 2. Shannon's diversity index for trees ranged from 1.37 to 2.44 for different forest types. The range of Shannon's index is reported to vary from 0.83 to 4.1 for the forests of the Indian sub-continent (Jha and Singh 1990, Pandey and Shukla 1999) and 1.99 to 3.99 for the forests of Western Ghats and montane temperate forests (Jayakumar and Nair 2013 and other references therein). The diversity index is generally higher in tropical forests, which is reported in the range of 5.06 to 5.40 for young and old strand, respectively (Knight 1975). For the forest ecosystems of Siwaliks, the diversity of tree species was higher in the *Shorea robusta* forests (1.37 to 2.42) and mixed dry deciduous forest (2.44 to 2.51) as compared to the pine and plantation forests (1.24 to 1.49).

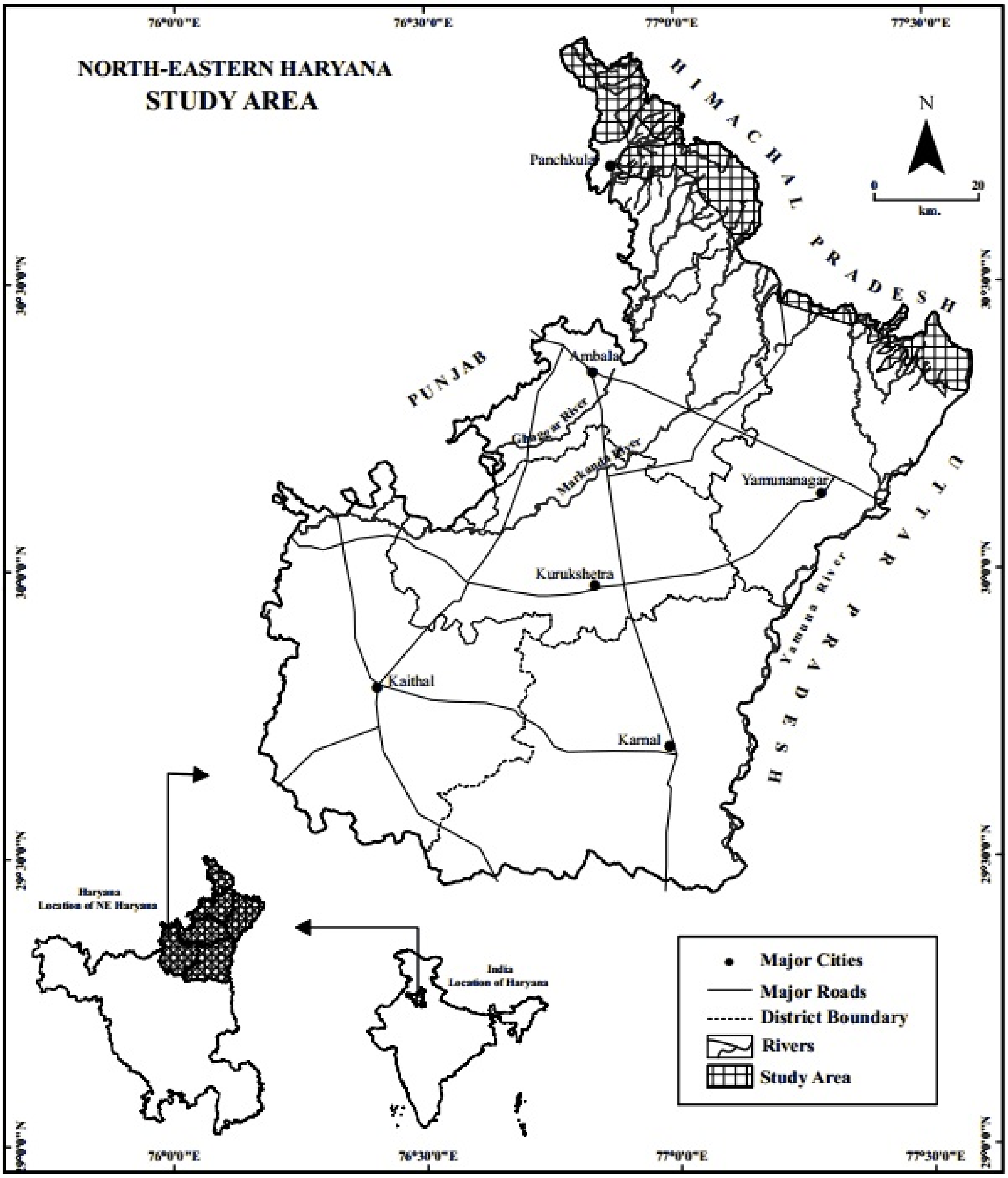


Figure 1. Panchkula Forest Division and Yamuna Nagar Forest Division in northeast Haryana.

The concentration of dominance for trees was greater in the plantation and pine forests (0.348 to 0.454) as compared to *Shorea robusta* forests and mixed dry deciduous forests (0.080 to 0.290; Table 2). The concentration of dominance values are higher than the average value of tropical forests (Cd= 0.06, Knight 1975). For the *Shorea robusta* forests at Kalesar, equitability index (Pielou's index) for trees was 0.66-0.83; the values being 0.896 to 1.579 for the mixed dry deciduous forest (Table 2). Species richness (Margalef's index) for the trees was maximum for the mixed dry deciduous forest (3.175 to 7.440) followed by that of *Shorea robusta* forests (1.74 to 2.12) and that of plantation and pine forests (1.064 to 1.744).

Table 1. Vegetation composition of forests of Siwaliks in north-east Haryana.(based on Kumar 2012, Gupta 2013)

| Forest type | Vegetation composition |
|---|---|
| Dry Plains *Shorea robusta* forest, Kalesar | *Shorea robusta* , *Mallotus philippensis, Ehretia laevis*, *Litsea glutinosa;* six shrub species; 23 herbaceous species |
| Dry Siwalik *Shorea robusta* forest, Kalesar | *Shorea robusta*, *Mallotus philippensis*, *Ehretia laevis*, *Diospyros tomentosa* ; predominant shrubs - *Lantana camara*, *Nepeta graciliflora*; 23 herbaceous species |
| Northeen dry mixed deciduous forest, Kalesar | *Diospyros tomentosa* Roxb., *Lannea coromandelica* Merr., *Anogeissus latifolia* ; shrubs -*Lantana camara, Thespesia* ; 33 herbaceous species |
| Plantation forests, Kalesar | *Tectona grandis* (IVI = 185); *Haplophragma adenophyllum* (IVI = 168); Nine shrub species; 15- 21 herbaceous species |
| Sub-tropical Siwalik chir pine forest, Panchkula | fores at an altitude of about 1200m in the Siwaliks, dominated by *Pinus roxburghii* (IVI= 193.4), Seven shrubs species; 43 herbaceous species |
| Northern dry mixed deciduous forest, Panchkula | *Anogeissus latifolia,* (IVI= 76.7); *Lannea coromandelica* (IVI=59.6), *Terminalia alata:* six shrub species; 43 herbaceous species |

Table 2. Shannon's diversity index (H) and Simpson's index (Cd), Margalef's index (D), and Pielou's Index (E) in *Shorea robusta*, mixed deciduous and plantation forests in Kalesar reserved forest in the Yamunanagar forest division , and subtropical Siwalik chir-pine forest in Panchkula forest Division of Haryana Siwaliks. (Based on Kumar 2012, Gupta 2013)

| Forest Type | Species Number | Shannon's index (H) | Margalef's index (D) | Simpson's index (Cd) | Pielou index (E) |
|---|---|---|---|---|---|
| Dry Plains *Shorea robusta* forest, Kalesar | 13-15 | 1.37-2.24 | 2.12-1.74 | 0.213-0.29 | 0.83- 0.66 |
| Dru Siwalik *Shorea robusta* forest , Kalesar | 10-17 | 1.61-2.42 | 1.971-2.68 | 0.139-0.268 | 0.70-0.83 |
| Northern dry mixed deciduous forest, Kalesar | 16-19 | 2.44-2.77 | 4.934-3.175 | 0.103-080 | 1.248-0.896 |
| Plantation forest, Kalesar | 8-10 | 1.49 | 1.064-1.356 | 0.348- 0.398 | 0.648- 0.718 |
| Sub-tropical Siwalik chir pine forest, Panchkula | 6 | 1.24 | 1.744 | 0.454 | 0.454 |
| Northern dry mixed deciduous forest, Panchkula | 24 | 2.51 | 7.440 | 0.191 | 1.578 |

A total of 156 species were recorded during sampling of the forest vegetation in both Yamunanagar and Panchkula forest divisions during August 2008 to December 2012, indicating moderately high diversity of the various functional groups of plants (trees, shrubs, herbs, and climbers) in the forests (Kumar 2012, Gupta 2013). Many of the plant species are a source of timber, forest products (including flavors and fragrances, fibers, and saps and resins), fuelwood, fodder, fibers, dyes, tannins, oil, and medicinal plants (Table 3). Species diversity in forests of Siwaliks often contribute to the economy of the local people by supplying material used for small-income generating activities, such as the sale of local foods, fodder, bhabhar grass and traditional medicines. Several forest trees and shrubs bear fruits that are used by the local people. Some important fruits include wild pear (*Pyrus pashia*), wild bel (*Aegle marmelos*), Amla (*Emblica officinalis*), and ber (*Zizyphus mauritiana*). The conservation of non-timber forest produce can promote sustainable resource use for improving the livelihood opportunities to local people. Rural Livelihood opportunities in Kalesar Reserved Forest are shown in Figure 2. These include Non Timber Forest Produce (NTFP), Medicinal plants, Bamboo Basket Making, Animal Husbandry, Bhabhar grass rope making, Food processing, Biogas Tree plantation/ agro forestry/ horticulture, and Nursery raising through shed net/poly house.

Table 3. Non Timber Forest Produce (NTFP) in forests of Haryana Siwaliks.

| Plant Species | Families | NTFP |
|---|---|---|
| *Anogeissus latifolia* (Roxb. ex DC.) Wall. | Combretaceae | Fodder, Fiber |
| *Acacia catechu*. (L.f.) Willd. | Mimosaceae | Medicinal, Fodder, Dye, Kath, Lac |
| *Adhatoda zeylanica* Medic. | Achanthaceae | used for cough and cold |
| *Bauhnia vahlii* W.&A. | Caesalpiniaceae | Fodder |
| *Cassia fistula* L. | Caesalpiniaceae | Medicinal, Dye |
| *Emblica officinalis* Gaertn. | Euphorbiaceae | Medicinal, Dye, fruits used as spices and condiment |
| *Holoptelea integrifolia* Planch. | Ulmaceae | Bark used as a cure for rheumatic pain |
| *Lannea coromandelica* Merr. | Anacardiaceae | Fiber, Dye and Gum |
| *Madhuca indica* J.F. Gmel. | Sapotaceae | Fodder, Medicinal, Edible flowers and fruits |
| *Mallotus philippensis* (Lamk.) Muell. | Euphorbiaceae | Dye, Medicinal |
| *Murraya koenigii* (L.) Spreng. | Rutaceae | Leaves used as spices and condiment, Medicinal |
| *Nyctanthes arbotristis* L. | Oleaceae | Medicinal, Dye, Fodder |
| *Ougeinia oojeinensis* Hochst. | Fabaceae | Gum, Fodder, Medicinal |
| *Shorea robusta* Gartn.f. | Dipterocarpaceae | Resin, Dye, Oil |
| *Terminalia bellirica* (Gaertn.) Roxb. | Combretaceae | Medicinal, Fodder, Dye, Resin |
| *Terminalia chebula* Retz. | Combretaceae | Medicinal |
| *Zizyphus mauritiana* Lamk. | Rhamnaceae | Fodder, edible Fruits |

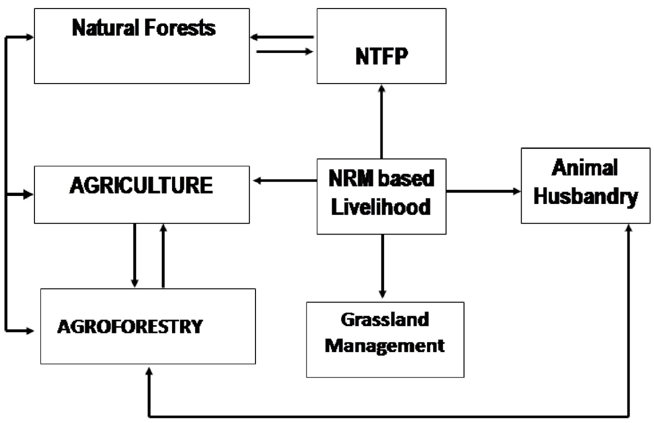


Figure 2. Linkages between biodiversity and livelihoods

## ECOSYSTEM SERVICES AND BIODIVERSITY CONSERVATION MECHANISMS

he ecosystem services are the benefits that the natural environment provides to humanity. The Millennium Ecosystem Assessment (MEA) highlighted the condition of ecosystem and ecosystem services, and distinguished four broad categories of ecosystem services, i.e., provisioning, regulating, cultural, and supporting services (MA 2005; Figure 3). The MA provisioning services describe the processes that yield foods, fibers, fuels, water, biochemicals, medicinal plants, pharmaceuticals, and genetic resources. The cultural services comprise a set of largely non-material benefits of the environment including recreation and tourism and the spiritual, religious, aesthetic, and inspirational well-being. The regulating services are the benefits obtained from regulation of ecosystem processes; include erosion control or soil stabilization, water purification, and waste treatment; air quality maintenance, climate regulation, hydrological flows, and natural hazard protection. The supporting services are those that are necessary for the production of all other ecosystem services (Figure 3). It is important to emphasise that supporting services differ from provisioning, regulating, and cultural services in that their impacts on people are indirect (Figure 3).

There is significant evidence to show the linkages between changes in biodiversity and the way ecosystems function. Recent ecological research has shown the linkages between biodiversity and ecological functioning, and analyzed ecological processes regulating a number of ecosystem services. The Economics of Ecosystems and Biodiversity (TEEB 2010), a major international study, drew attention to the global economic benefits of biodiversity, and highlighted the growing costs of biodiversity loss and ecosystem degradation. Since most of the ecosystem services are not a part of

| PROVISIONING SERVICES | CULTURAL SERVICES |
|---|---|
| Products obtained from the natural ecosystems:<br><br>•Food<br>•Wood, fuel and fibre<br>•Medicinal plants, pharmaceuticals<br>•Genetic resources<br>•Ornamental resources<br>----- | Non material benefits that contribute to wider needs and desires of society:<br><br>•Aesthetic values<br>•Spiritual and religious<br>•Educational<br>•Recreation and tourism<br>----- |
| **REGULATING SERVICES** | **SUPPORTING SERVICES** |
| Benefits obtained from regulation of ecosystem processes, rarely given a monetary value in conventional markets:<br><br>•Climate regulation<br>•Flood control<br>•Water regulation and purification<br>•Bioremediation of wastes<br>•Pollination<br>----- | Necessary for the production of all other ecosystem services:<br><br>•Nutrient cycling<br>•Primary production<br>•Soil Formation<br>•Water cycling<br>•Provision of habitat<br>•Production of atmospheric oxygen<br>----- |

Figure 3. The four types of Ecosystem Services (From: MEA 2005)

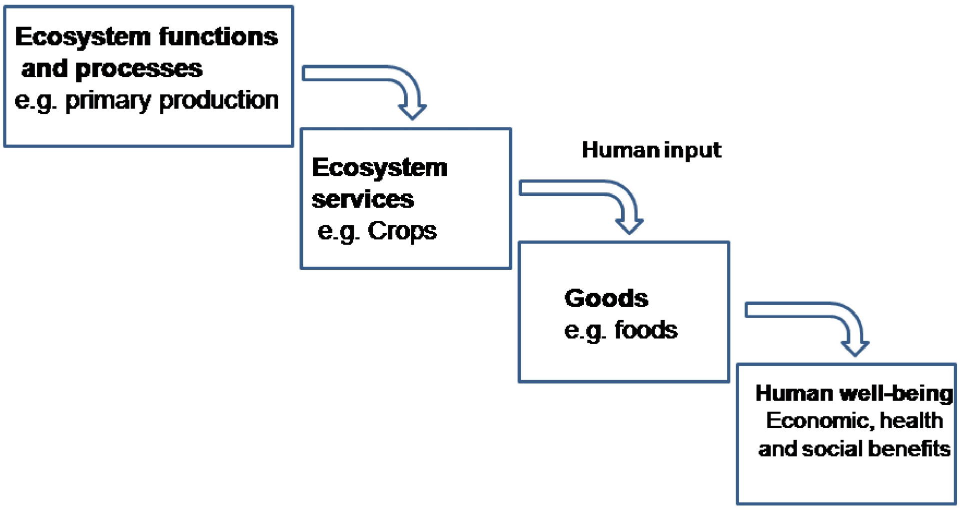


Figure 4. Conceptual framework of ecosystem services to show a multilayerd relationship. (based on Mace et al. 2012)

the commercial market, they are often given little weight in policy decisions. Based on a review of more than 1,700 papers, Cardinale et al. (2012) have analyzed the impact of biodiversity loss on the goods and services provided by ecosystems.

Biodiversity regulates all ecosystem services, but it can also be a service in itself (e.g. the existence value of a species under cultural services) (Mace et al. 2012). Biodiversity is also considered to have insurance value by providing resilience in the face of current or future changes in ecosystems and the services they provide. Ecosystem services provide outputs or outcomes that directly and indirectly affect human well-being and these considerations can link well being by taking into consi-deration an economic approach. This concept of value focuses on the contribution to human welfare, which is seen as the most relevant to policy-making. Ecosystem services can be valued in monetary (market and nonmarket) and non-monetary terms to demonstrate their contribution to economic, health and social well-being (Haines-Young and Potschin 2010). For conservation of biodiversity, it is important to show the relationship between bio-diversity and ecosystem services (Figure 4) and the importance and value of ecosystem services provided by sites important for biodiversity. For valuing biodiversity, economists have developed various tools to estimate the value of natural and managed ecosystems, and the market and non-marketed services (see Peh et al. 2013). There is need to link biodiversity and ecosystem functions (BEF) and the biodiversity and ecosystem services (BES) perspectives as services are often regulated by multiple functions (Mace et al. 2012) .

The main services from forest ecosystems include: habitat provision, clean water, flood protection, carbon sequestration and storage, climate regulation, oxygen production, nutrient cycling, genetic resources for crops, and spiritual, cultural, recreational and tourism values. The ecosystem services approach can save many forest ecosystems with high biodiversity and willingness of society to protect their biodiversity.

The forest ecosystems also play an important role to support and regulate environmental conditions through processes of pollination, water purification and provi-ding cultural and aesthetic benefits from local to regional scale. Ecosystem services improve local well-being by providing clean water and productive agricultural systems besides contributing to development by encour-aging nature-based tourism. For securing food, fresh-water and raw material, land-use is the key to ecological sustainability. Some land-use practices such as agri-culture and grazing lands allow some ecosystem goals to be more readily appropriated by human society, which gives economic and social benefits. The critical ecosystem services such as the supply of non-timber forest products, the diversity of pollinating insects and soil carbon stocks as well as the regulation and purification of water flows are essential for sustainable forest management in this region of unstable Siwaliks.

The small habitation in the Kalesar Reserved forest is located on the Poanta - Sahib Yamunanager highway. The rural settlement of the Kalesar village is widely scattered in the areas adjacent to the National park and the wild life sanctuary area. The size of population is small and generally people have low income levels. There are 220 households (87.21% belonging to scheduled caste and scheduled tribes). About 50% of the population of the Kalesar village lives below the poverty line according to the microplanning report of the Haryana Forest Department (2005). Most of the villagers are engaged in animal husbandry, agriculture, growing of medicinal plants, small cottage industry, and employed in the protected areas. The main crops grown by the farmers are paddy, wheat, sugarcane and millets. Panchkula forest division being surrounded by human habitation is under tremendous biotic pressure.

The relationships between biodiversity and poverty alleviation have been extensively studied in diverse types of ecosystem and recently reviewed (see Leisher et al. 2010). These workers have identified biodiversity conservation and poverty reduction mechanisms on the basis of specific interventions, which are indicative of providing benefit to the poor in rural areas as well as conserving biodiversity. Some of mechanisms for biodiversity conservation and poverty alleviation as applicable to forest ecosystems of Siwaliks are summarized as follows:

**(i) Non-Timber Forest Products**

These are any commodity obtained from the forest which include seeds, fruits , oils, foliage, medicinal plants, fibers, saps and resins, fuelwood and forage. Adibadri, Chuharpur Herbal Park in the Siwaliks harbour a rich diversity of medicinal plants that are source of local medicines, and play an important role in employment generation. Several important pharmaceuticals have originated as plant-based substances, which are of incalculable value for human health.

**(ii) Nature-Based Tourism**

The nature-based tourism includes community-based operations, eco-lodges and safari operations. Haryana Forests Department has taken a lead in developing the very beautiful nature camps at Thapali, Lal Munia Rest House and Morni fort in Panchkula district and Kalesar, Bansantor, Herbal Park, Chuharpur in Yamuna Nagar district. The ecotourism programs at these locations could be instrumental to minimise the negative aspects of conventional tourism on the environment and enhance the cultural integrity of local people besides providing livelihood to villagers.

**(iii) Protected Areas**

This conservation mechanism is focused on the poverty reduction benefits that flow directly from protected areas themselves. There are multiple benefits provided by protected areas. The employment generation directly benefits the local people and can play an important role to reduce poverty.

**(iv) Agroforestry**

Agroforestry is a dynamic, ecology based land-use system in which trees are incorporated into the agricultural landscape in order to obtain economic and ecological benefits. The service functions of agroforestry are in control of soil erosion, wind breaker, maintenance and improvement of soil fertility, control of weeds and fencing, and carbon sequestration in soil. Agroforestry has potential to store carbon in plant biomass and wood products. .Agroforestry has the potential to diversify and improve income through the harvest of tree products or by providing enhanced soil and hydrological functions for the existing cropping systems.

**(v) Grazinglands**

There is interdependence between the grazers, the grass productivity, and the biodiversity in the grassland systems. The *Saccharum munja* dominated grassland in the riparian zone in the Kalesar Reserved forest and open grazing lands in the Morni hills are basis for pastoral economy of the local people along with protecting rich diversity of plants.

**(vi) Agro-biodiversity**

The most important agro-biodiversity elements are traditional landraces that are uniquely adapted to local conditions such as soil characteristics, rainfall, diseases and pests. The genetic diversity can play a very important role to reduce poverty by conserving the local land races.

- Genetic biodiversity improves agricultural productivity
- Ecosystem resiliency sustains land and water productivity
- Biodiversity increases adaptive capacity of agricultural production to stresses
- Biodiversity sustains essential functions such as pollination, pest/disease regulation, nutrient recycling.
- In-situ agrobiodiversity conservation generally helps poor farmers to diversify the types of crops in the cropping systems.

**(vii) Payments for Environmental Services (PES) :**

Payments for environmental services (PES) are voluntary transactions where a well-defined environmental service is bought by an environmental service buyer from an environmental service provider if and only if the environmental service provider secures environmental service provision (Richards and Jenkins 2007). PES can include bio-prospecting, eco-labelling, conservation easements, conservation concessions, watershed protection, and carbon sequestration or storage (Richards and Jenkins 2007). Markets and financial mechanisms that compensate local populations which take on the responsibility of protecting and sustainably managing nature at its source have the potential to provide monetary benefits to poor communities who need it most (Turner et al. 2012). PES as applicable to Siwaliks are watershed protection and carbon sequestration or storage.

## CARBON STORAGE IN FORESTS AS AN ECOSYSTEM SERVICE

The forest ecosystems are an important sink for carbon storage, which is an indicator of regulatory ecosystem services. The forest ecosystems sequester carbon from the atmosphere and influence the patterns of climate. Climate regulation refers to the influence that ecosystems have on the global climate by emitting greenhouse gases to the atmosphere or extracting carbon form the atmosphere. The various pools of carbon in the forest ecosystems include aboveground woody biomass, belowground biomass, litter fall, ground floor litter and soil carbon. Aboveground woody biomass represents the largest pools of carbon in tropical forests. Forests have the potential for sequestering carbon, primarily carbon accumulated within the vegetation. The soil carbon pool has a potential for carbon storage in soil. The carbon pool in aboveground biomass, below ground biomass, litterfall, fine root biomass and soil microbial biomass and soil in the forest ecosystems of Yamunanagar forest division have been estimated (Table 4). The above-ground carbon pool was maximum accounting for 60.93% to 73.64% of the total vegetation carbon pool followed by below ground carbon stock varying from 16.42% to 17.33% (Table 4). Although contribution of fine roots carbon stock towards total carbon stock is small, i.e., 0.33% to 1.50% but, plays an important role in organic matter dynamics and forest nutrient cycling. The carbon content of trees differed considerably due to variation in biomass of tree components and the plant species in the major forest types of Yamunanagar forest division (Table 5). The aboveground carbon pool was 81.36 to 85.45 % of total carbon pool in different forests. The carbon pool in the plains *Shorea robusta* and Siwalik *Shorea robusta* forest was mainly contributed by four tree species, i.e., *Shorea robusta, Mallotus philippinsis, Ehretia laevis, Terminalia alata;* Their contribution varied from 89 to 90%. Only 9 to 10 % biomass carbon pool was contributed by other species (n= 20 to 28) found in different forests. In the mixed forest , the contribution of the predominant species was in the order: 54.51% *Anogeissus latifolia* > 9.95 % *Diospyros tomentosa* > 2.97% *Holoptelea integrifolia* > 1.96 % *Garuga pinnata* (Table 5).

Table 4. Carbon pool (Mg C $ha^{-1}$) in vegetation and soil in various forest types of Yamunanagar Forest Division in northern Haryana. (based on Kumar 2012)

| Plant/Soil components | Dry Plain *S. robusta* forest | Dry Siwalik *S. robusta* forest | Dry mixed deciduous forest |
|---|---|---|---|
| Aboveground biomass | 134.58 | 217.54 | 51.76 |
| Belowground biomass | 31.72 | 48.55 | 14.77 |
| Fine roots | 1.15 | 0.98 | 1.28 |
| Ground Floor litter | 3.09 | 3.26 | 2.78 |
| Soil Microbial biomass | 0.63 | 0.68 | 0.54 |
| Soil organic carbon | 20.51 | 21.89 | 17.07 |
| Total | 191.68 | 292.90 | 88.20 |

Table 5. Contribution of predominant tree species to plant carbon pool (Mg C $ha^{-1}$) in various forest types of Yamunanagar Forest Division in northern Haryana (based on Kumar 2012)

| Tree species | Aboveground biomass | Belowground biomass | Total biomass |
|---|---|---|---|
| Dry Plains *Shorea robusta* forest | | | |
| *Shorea robusta* | 147.31±6.77 | 33.88±1.42 | 181.19±8.19 |
| *Mallotus philippinsis* | 1.73±0.67 | 0.38±0.14 | 2.11±0.81 |
| *Ehretia laevis* | 6.97±0.32 | 1.67±0.04 | 8.64±0.36 |
| *Terminalia alata* | 4.63±0.21 | 0.87±0.04 | 5.50±0.25 |
| Others (n=20) | 19.07±0.87 | 4.38±0.19 | 23.45±1.06 |
| Dry Siwalik *Shorea robusta* forest | | | |
| *Shorea robusta* | 224.55±25.41 | 37.62±5.84 | 262.17±31.25 |
| *Mallotus philippensis* | 22.49±2.54 | 4.11±0.55 | 26.60±3.09 |
| *Ehretia laevis* | 10.63±1.20 | 1.86±0.26 | 12.49±1.46 |
| *Terminalia alata* | 7.07±0.80 | 1.34±0.18 | 8.41±0.98 |
| Others (n=28) | 29.07±3.29 | 5.09±0.72 | 34.16±4.01 |
| Dry mixed deciduous forest | | | |
| *Anogeissus latifolia* | 58.84±4.29 | 13.53±0.81 | 72.37±5.1 |
| *Diospyros tomentosa* | 10.74±0.78 | 2.25±0.14 | 12.99±0.92 |
| *Holoptelea integrifolia* | 3.21±0.23 | 0.67±0.03 | 3.88±0.26 |
| *Garuga pinnata* | 2.12±0.15 | 0.44±0.03 | 2.65±0.18 |
| Others ( n=30) | 13.27±0.96 | 2.78±0.17 | 16.05±1.13 |

The total carbon storage and carbon accumulation in the soil-plant system as indicator of regulatory eco-system services in the natural *Shorea robusta* forest and plantation forests in Yamunanagar forest division are given in Table 6. The natural forest showed distinctly higher carbon storage (plant biomass =147.33 Mg C $ha^{-1}$; soil =35.10 Mg C $ha^{-1}$) than the plantation forests (plant biomass =40.56 to 53.00 Mg C $ha^{-1}$: soil =27.26-29.18 Mg C $ha^{-1}$). The forests stored 149.82 to 540.20 Mg $CO_2$ $ha^{-1}$ in plant biomass and 99.95 to 128.70 Mg $CO_2$ $ha^{-1}$ in soil, which could account for 668.9 carbon credits $ha^{-1}$ in the natural forest and 253.15 to 294.28 carbon credits $ha^{-1}$ in the plantation forest. Assuming the price of $10 per Carbon Credit, the monetary value of carbon storage comes to range from US$ ~6689 to 2515 $ha^{-1}$. The carbon sequestration benefits through annual carbon flux in the three forests ranged from 28.23 to 40.19 Mg $CO_2$ $ha^{-1}$ $yr^{-1}$, the values being greater for the natural forest as compared to that of the plantation forests (Table 6). The forests have appreciable carbon sequestration potential in the plant-soil system which could play an important

Table 6. Carbon storage potential (Mg C $ha^{-1}$) in the plant and soil (0-60 cm layer) system and annual carbon flux (Mg $CO_2$ $ha^{-1}$ $yr^{-1}$) as indicator of regulatory ecosystem services in terms of carbon sequestration in the natural and plantation forests at Kalesar forest Reserve (based on Gupta 2013)

| Forest Type | Carbon Storage | | Annual Flux | $CO_2$ Sequestration as Carbon Storage | | $CO_2$ Sequestration as Annual Flux |
|---|---|---|---|---|---|---|
| | Plants | Soil | Plants | Plants | Soil | Plants |
| *Shorea robusta* forest | 147.33 | 35.10 | 10.96 | 540.20 | 128.70 | 40.19 |
| Plantation forest - *Tectona grandis* | 40.86 | 29.18 | 7.70 | 149.82 | 103.33 | 28.23 |
| Plantation forest - *Haplophragma adenophyllum* | 53.00 | 27.26 | 8.29 | 194.33 | 99.95 | 30.40 |

role in climate change mitigation and adaptation. Maintaining the stores and sink of carbon in the forest ecosystems can play key role to reduce future emission of greenhouses gases.

The MODIS data set combined with forest density and vegetation type used in the regression model captured the amount and spatial distribution of above-ground biomass in different forest ecosystems of Yamunanager and Panchkula forest divisions in Siwaliks of northern India. Predictive modelling of the above-ground biomass and the spectral data under investigation showed significant linear relationship (Kumar et al. 2011). Integrating remote sensing and field inventory data has been a useful approach to obtain consistent, reliable and comparable spatial analysis across land-scapes for improved forest aboveground biomass (AGB) estimates, and a practical and effective technique for mapping the AGB distribution that are necessary for regional carbon stock assessment and carbon seques-tration - an important ecosystem service of the forest ecosystems on regional basis. The total AGB was 26.99Tg accounting for a total carbon stock of 12.96 Tg in the forests of northern Haryana. The forests store 129,600 Mg of carbon or 464,622 Mg of carbon dioxide, which could account for 464,622 carbon credits. Assuming $10 price for one Carbon Credit, the monetary value of biomass carbon comes out to be ~US$ 4,646,220.

Current rapid economic development and major land use and land cover changes are leading to increased conflicts between population growth and demand on natural resources, and impose significant challenges in managing carbon storage through application of different tree species and age structures can be a realistic and effective strategy for sustainable forest management. Maintaining the stores and sink of carbon in the natural ecosystems can play key role to reduce future emission of greenhouses gases (Lewis et al. 2009). Forests will help in adaptation to climate change by increasing resilience of people and ecosystems. To provide ecosystem services for strong carbon sinks will require formalizing and enforcing land rights along with payment of ecosystem services for forest dwellers living near forested areas (Lewis et al. 2009). The links between carbon sequestration, livelihoods and ecosystem services in Siwaliks are summarised in Figure 5. Thus, protection of forest ecosystems would serve as carbon store in the long-term. Mitigation and adaptation options in the forest sector need to be fully understood and used in the context of promoting sustainable development.

## INTEGRATED WATERSHED MANAGEMENT: A CASE STUDY OF BENEFIT SHARING

Sukhomajri village located in the Siwaliks, the foothills of the western Himalayas, was amongst the first in India to test participatory watershed management (Agarwal and Narain 2000, Sengupta et al. 2003, Agarwal and Narain 2010). These workers documented that the entire agricultural land of Sukhomajri village was under rain-fed single cropping without irrigation up until 1975. There was sparse vegetation, poor farm land, and a great deal of soil erosion and runoff. Small land holdings of the villagers suffered due to frequent crop failures because of erratic distribution of rainfall in the Siwaliks (Sengupta et al. 2003). The open grazing by the livestock suppressed regeneration of trees and kept the surroun-ding hills and watersheds bare. Practices of free grazing of cattle, forest land clearance and tree-felling on the hill slopes caused the continuing problem of siltation in the man-made Lake Sukhna near Chandigarh.

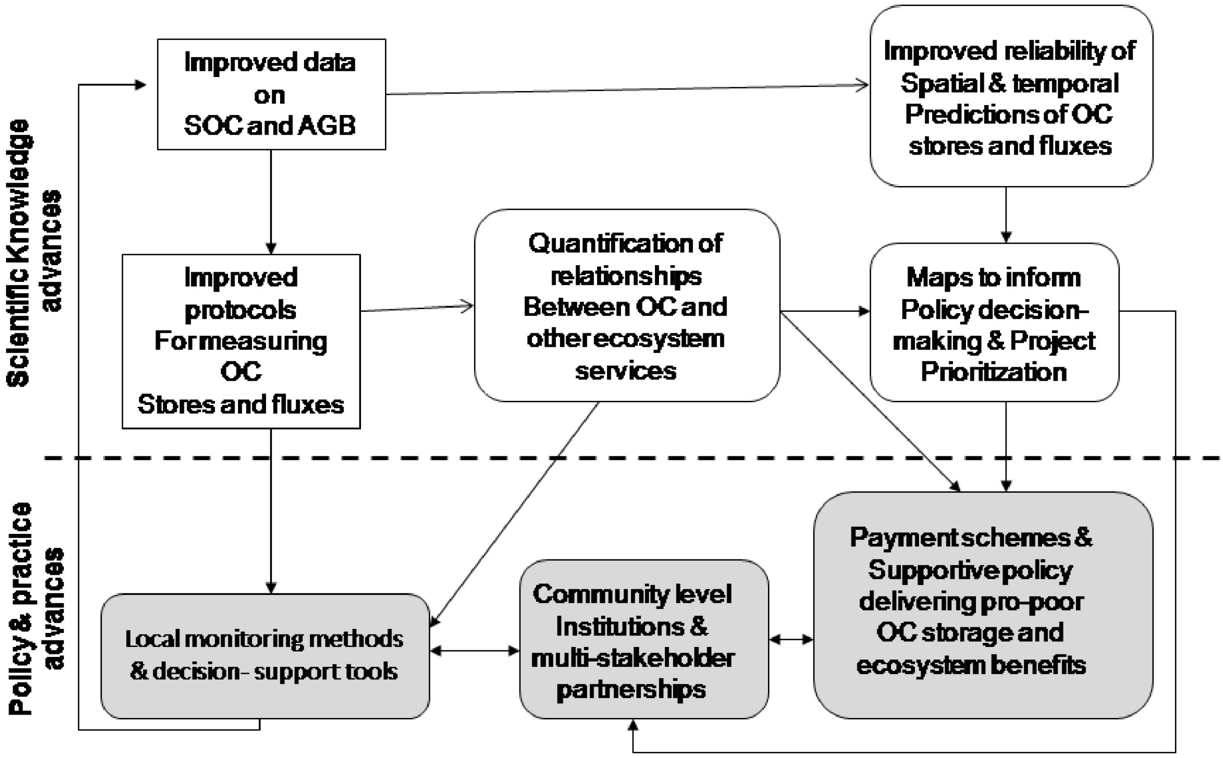


Figure 5. Linking carbon sequestration, livelihoods and ecosystem service provision in Siwaliks (based on Stringer et al. 2012)

A scheme was launched in 1979 in response to growing water scarcity faced by the farmers upstream, and to stop siltation of the Sukhna Lake downstream. Farmers in Sukhomajri were supported by the CSWCRTI and the Ford Foundation to undertake a programme of checking dam construction and watershed management to tackle heavy siltation and low dry seasonal flows. The mechanical measures reduced the runoff sediment from the highly eroded hills of the Shivaliks. The planting tree of species like khair ( *Acacia catechu*) and shisham ( *Dalbergia sissoo*) in pits and bhabbar grass (*Eulaliopsis binnata)* on mounds of trenches improved green cover of the denuded hills. The planting of *Agave americana* and *Ipomoea carnea* was undertaken to control erosion. Social fencing among the farmers gained wide recognition in the effort to control the grazing of cattle in the forests. The involvement of local people and the efforts of CSWCRTI, Dehradun, and Ford Foundation were important inputs for implementing the project (Agarwal and Narain 2000).

Under the Sukhomajri watershed development program, tree density on denuded slopes of lower Siwaliks increased from 13 to 1292 per hectare, over a period of 16 years. There was increase in the production of forest grasses resulting in a six fold increase in milk production, while better-regulated water flow permitted more diverse and higher yielding cropping systems (Agarwal and Narian 2000, Agarwal and Narian 2010). As a direct result of the increased economic activity, household incomes across all social classes increased by 50%. Further downstream, the siltation rate of the Sukhna Lake near the city of Chandigarh was reduced by 95%, saving the city of two hundred thousand US dollars annually in dredging and other costs (Agarwal and Narian 2010). The economic improvement and environmental benefits of watershed management are summarised in Table 7 on the basis of report by Porras and Neves (2006).

The ecosystem services considered in this case are soil preservation, afforestation, ground water protection and forest management. The case of watershed protection in Sukhomajri village in Siwaliks is especially relevant from the point of view of developing market-based approaches for watershed protection services and improving livelihoods in India (Agarwal and Narian 2010). According to Sengupta et al. (2003) as cited in Agarwal and Narian (2010), in the case of watershed management, the potential for payments and market-like

Table 7. Economic improvement and environmental benefits of watershed management (from Porras and Neves 2006).

| Parameter | Duration | Improvement |
|---|---|---|
| Crops Yield | 1977- 1986 | The yield rates of wheat and maize, increased by more than 50% |
| Bhabhar Grass | 1976-1992 | 40 kg per hectare to 3 Mg per hectare |
| Milk Production | 1976-1992 | The daily milk production rose from 334 L to 579 L due to shift in livestock from goats to buffaloes. |
| Trees Density | 1976-1992 | In the watershed, the number of trees increased from 13 ha-1 to 1,292 ha-1 |
| Environmental benefits : Avoided costs | - | Raising the value of the forest to US$20 million capable of generating at least US$700,000 per annum. |
| Environmental benefits : Avoided costs | - | Siltation in Sukhna Lake decreased by 95%; saving the city of Chandigarh about US$200,000 annually in dredging and related costs |
| Social Benefits | - | Improved living conditions, Benefit sharing (water, fodder grass) |

arrangements for watershed protection services can be observed at two levels simultaneously, one between the downstream city of Chandigarh and upstream villages like Sukhomajri, and secondly through an "embedded" market for water within Sukhomajri village. The success story of Sukhomajri watershed management has been replicated in the entire region of Siwaliks of Northern India to improve livelihood opportunities to the local people. .

**Managing Watershed Externalities**

Watershed projects also create their own externalities, which cause uneven distribution of costs and benefits that undermine project objectives and harm the poor (Kerr et al. 2006).Theoretical Approaches for Internalizing Externalities, according to Kerr et al. (2006) are summarized below:

- Awareness creation
- Moral Suasion and Social Conventions
- Investment subsidies
- Regulatory limits and fines
- Indirect benefits, mergers
- Payment for environmental services
- Changing and/or strengthening property rights
- Negotiation and conflict resolution

To strengthen local governance systems to support capacity building to manage watershed projects locally instead of central authority.

## CONCLUSIONS

Biodiversity provides many benefits to people via ecosystem services. The provision of these services is linked to the state of biodiversity, and human pressures on biodiversity. Policy and management responses from the local to the national level can reduce such anthropogenic pressures by implementing practicable strategies for sustainable use and benefits from biodiversity. Moreover, biodiversity-related resources have non-use values to people that need to be reflected in landuse decisions without compromising local economic development. The long term conservation of the biodiversity can only be ensured by creating public awareness about the value of biodiversity and allocating a greater share of benefits to the village poor from conservation. Ecotourism, recreation and education can help in sustainable use and management of biodiversity. There is need to formulate public policy to encourage the use and conservation of biodiversity in a way that reflects its relative value in relation to sustainable livelihoods of rural poor on a regional basis. The annual value of ecosystem services can be used to make informed decisions and policies to help conserve forests, biodiversity and ecosystem services to improve human-well being.

The biodiversity policy must take into account both private and public values of biodiversity, as well as its consequences for all the stakeholders keeping in view the specific institutional, economic and social needs. Policy options must be systematically analyzed to minimize the costs of public administration, monitoring and enforcement, as well as the costs of implementation of biodiversity conservation programmes. The policy initiatives are needed to address trade in biodiversity-based products and services, improved genetic diversity for agriculture, and green jobs in agriculture, forestry, and ecotourism. Long-term conservation of the biodiversity can be ensured by creating public awareness about the value of biodiversity and allocating a greater share of benefits to the village poor from conservation. Creating public awareness on various aspects of biodiversity conservation at the grassroots level is necessary for the involvement of people in effective conservation of biodiversity.

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